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Agricultural Memorandum No 757

FROST SURVEYS - A REVISED METHOD OF ANALYSIS

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INTRODUCTION

A Frost Survey is normally made with the co-operation of ADAS and the farmer or grower concerned in order to determine the Spring frost risk over a piece of land, and in particular the variation of this risk from point to point. The area surveyed may be anything from a few acres up to 200 acres or more; in a typical case the terrain will be irregular with known or suspected cold air drainage effects, and the management of a high-return but frost-sensitive crop will be involved.

The established technique is to take daily readings during April and May of minimum temperature at a number of points over the area being surveyed, normally in a single year or very occasionally in 2 successive years, and from this sample to deduce long-term frequencies of the occurrence of frost. These frequencies can be expressed in various ways; current practice is to give "the number of years in 10 of at least one occasion" for 3 threshold temperature levels (32^{o}, 30^{o} and 28^{o}F) after starting dates at weekly intervals from 1 April. The period in each case ends on 26 May, effectively the end of the frost season except in very abnormal years. This presentation has already been commented upon by the author in Ag Mem No 731.

The field work is fairly straightforward, though care must be taken in the selection of thermometer sites in order to bring out the salient points without using an excessive number. Sheathed minimum thermometers in simple shielded mounts are used (see Figure 1), and at one site only an additional minimum thermometer in a standard screen is installed so as to provide a daily correction for the slightly non-standard exposure of the survey thermometers. A condition of undertaking the survey is normally that the farmer or his nominee is willing to take the daily readings; this somewhat onerous task is usually carried out conscientiously and a reliable set of readings provided. The interpretation of the readings is however not at all straightforward and it is with this aspect of the survey that this Memorandum is largely concerned.

THE PROBLEM

Long-term frequencies of minimum temperature cannot be derived directly from observations made in a small number of years, and an indirect approach has to be used. The simplest way is to choose an established observing station in the same general area which has records going back 20 years or more and to use this as a reference or "base" station. Comparing the readings taken on the survey area with the corresponding ones for the base station allows a weighting factor to be calculated which can be applied to the long-term frequencies for the base station to give the required values for the site under analysis. In fact this is much more difficult than it appears: whilst it is accepted that the principle is sound, the handling of the weighting process has been a source of trouble for years, and though various methods have been tried none has inspired complete confidence.

The real problem is one of verification. Tests of a particular method are necessarily limited to comparisons between established observing stations and it is extremely difficult if not impossible to prove that the right answers will be obtained under all circumstances. It is only possible to try to ensure that the method is sound and that the results look reasonable.

DISCUSSION

After a long series of tests using observations from Long Ashton and Ross-on-Wye, J W Davies concluded that comparing the weekly means of daily minimum temperatures at the site under analysis and the base station gave the best results (see Ag Mem No 533). This method has been in use at Bristol for the past 2 years but it is now felt that the results are not satisfactory in all cases.

The first point to note is that it is somewhat misleading to talk of weekly means. The whole process is cumulative backwards in time so that only in the last week of the 8-week period is a single week's mean used; by the time the starting date of 1 April is reached a mean for the whole period is being used. There is now considered to be no advantage in this; within the limitations of the sampling procedure a single mean for the whole period applied to each of the 8 separate frequency curves gives equally good if not better results.

Returning to the basic assumption, in the simplest terms this says that if for example Site X shows in the sampling period a mean minimum of 2° below that for the base station, then in the long term (accepting necessarily that the sample mean is a close approximation to the true mean) Site X reaches a threshold temperature of say 30° just as many times, or in as many years, on the average as the base station reaches 32°. Suppose however that Site X is frost-prone and on cold nights in Spring is usually much more than 2° colder than the base station; one begins to suspect that something is wrong.

It is now held that the assumption only holds good if the long-term frequency distribution curves of minimum temperatures are of identical shape at the 2 places being compared, though their locations with respect to the temperature axis may be different. They need not necessarily follow the normal curve, though over flat country in Spring near-normal distributions are likely. However it follows that if the relationship does exist, the daily observed differences in a representative sample will show a normal distribution. If it can be assumed, as seems reasonable, that the converse is also true it becomes possible to identify such cases.

In Figure 2 the curve for Site A is approximately normal, indicating by the reasoning given above that the use of mean daily differences would give satisfactory results. The curve for Site B is obviously bi-modal; 2 separate distributions are present, the right-hand one being made up of differences occurring on radiation nights. The use of the overall arithmetic mean (3°F) is clearly not justified in this case, even if its value were not affected by the number of radiation nights in the sample, which it is.

A MODIFIED APPROACH

It has now been established that there is an identifiable class of situation for which the use of mean differences may be retained. In fact such situations are not at all unusual and include the relationship between Long Ashton and Ross-on-Wye, which explains why Davies' tests were successful. The difficult situations met with frequently in Frost Surveys do not however fall into this category.

Whilst not all cases are as simple as the bi-modal one which has been demonstrated, it is now considered that improved accuracy can be achieved using the mean of the differences on radiation nights only, provided that some allowances can be made for wind frosts (when differences tend to disappear). If the base station is close at hand the differences can be found directly. If it is more remote then variations of cloudiness will upset the assessment of radiation nights and a 2-stage comparison is envisaged, using a selected site in the Survey as a "sub-base". The simplified form of Davies' method can then be used for the sub-base.

The precise details of the latter arrangement have yet to be settled but should present no problems. In the meantime a survey carried out this Spring at Luddington Experimental Horticulture Station (near Stratford-on-Avon) provided a good opportunity to develop and use the direct method - the base station being Luddington itself. A full account is given below.

THE 1975 LUDDINGTON SURVEY

The preparation of the required frequency curves for the meteorological station at Luddington has already been dealt with in Ag Mem No 731. The survey was planned by Mr J Ingram, the Deputy Director, and all the field work was carefully done by the Station staff. Twenty-two minimum thermometers were sited as shown in Figure 3 and daily readings were made from 2 April to (exceptionally this year) 2 June. Site No 1 was near the existing screen (the base station in this case). Overhead irrigation for frost protection was carried out on a few nights and the readings of one or two thermometers in the irrigated area were corrected by interpolation.

ANALYSIS

An objective definition of a radiation night was required and this was taken to be a night when the screen minimum temperature minus the grass minimum temperature was $5^{\circ}F$ or more. The long-term Luddington records showed that this figure was reasonable; as shown in Table 1 a high proportion of cold nights fell into this category. Using this criterion 18 radiation nights were identified and the mean differences from Site 1 on these nights are shown in Figure 4.

Included in the long-term frequencies for any station will be some low temperature, windy occasions (ie near or actual wind frosts) when temperatures will be nearly uniform over considerable areas. Such occasions should be exempt from weighting and Table 1 provides a way of ensuring this: before the mean difference was applied to the frequency curves in any particular case it was first adjusted by taking the appropriate percentage given by the Table. This procedure is mathematically correct but makes the rather sweeping assumption that the average difference between sites is zero in the long-term for all occasions when the screen-grass minimum temperature difference is less than $5^{\circ}F$. The effect on the resultant frequencies is however relatively small and further refinement seems unnecessary.

THE LUDDINGTON RESULTS DISCUSSED

Table 2 gives a small selection of the results obtained by various methods. Only values for the threshold temperature of $28^{\circ}F$ are shown; for many crops this is the most important level.

Comparing the A and B values for the 3 sites given, the increase in frequency obtained by considering radiation nights only is much more in line with expectation, bearing in mind that Site 18 for example showed a mean difference on such nights of $2.2^{\circ}F$ with a maximum difference of $4.6^{\circ}F$ (the overall mean difference being $0.9^{\circ}F$).

Using Ross-on-Wye as a base station gave rather low values for Luddington (Site 1

B and C) although the differences between the 2 stations showed a near-normal distribution indicating that the use of the overall mean difference was permissible. Variations of cloudiness were probably the main cause, but in any case Ross and Luddington are over 40 miles apart and a nearer base station could have been used if necessary.

The values given in line D were the result of an experiment to see if sampling on a small number of nights would give satisfactory results. In retrospect (using the Daily Weather Reports) 9 nights were selected on the basis that a reasonably reliable forecast could have been made the afternoon before of low-temperature radiation conditions. Five of these were selected at random and the mean differences on these nights for all sites was acceptably close to those obtained using 18 nights. This method has been used in Israel (where presumably the risk of wasted journeys is not so great) and opens up the possibilities of getting quite good results using portable instruments in cases where a full fixed survey is not possible.

CONCLUSIONS

It is now felt that a more satisfactory way of evaluating Frost Surveys has been developed. All concerned are agreed that the Luddington results are realistic, and the method of analysis will be adapted for use on commercial holdings as the opportunity arises.

It would of course be useless to pretend that a high standard of accuracy can be achieved, particularly as year-to-year variations of cropping and soil moisture status make the sampling procedure even less representative. Nevertheless the information given to the grower is very valuable and well worth the effort involved.

NOTES ON USE OF FAHRENHEIT SCALE

The continued use of this scale may cause surprise. It is however still in common use by horticulturalists, while for economy's sake Fahrenheit thermometers have been retained in use until replaced through normal wastage (thus guaranteeing their invulnerability).

Any comments or suggestions will be welcomed and should be sent direct to the Author.

September 1975

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TABLE 1 LUDDINGTON 1951-1974. PERCENTAGE OF OCCASIONS WHEN SCREEN MINIMUM TEMPERATURE - GRASS MINIMUM TEMPERATURE $\geq 5^{\circ}F$

Periods from starting date shown to 26 May in each case

TEMP LEVEL	STARTING DATE							
	APR 1	APR 8	APR 15	APR 22	APR 29	MAY 6	MAY 13	MAY 20
	PER CENT							
$\leq 36^{\circ}F$	60	72	82	84	85	85	85	93
$35^{\circ}F$	67	79	85	86	87	88	88	96
$34^{\circ}F$	78	84	87	88	88	90	91	98
$33^{\circ}F$	85	88	89	89	91	92	94	100
$32^{\circ}F$	85	91	94	94	95	96	96	100
$31^{\circ}F$	86	92	97	97	98	98	98	100
$30^{\circ}F$	86	93	100	100	100	100	100	100
$29^{\circ}F$	86	94	100	100	100	100	100	100
$28^{\circ}F$	86	96	100	100	100	100	100	100

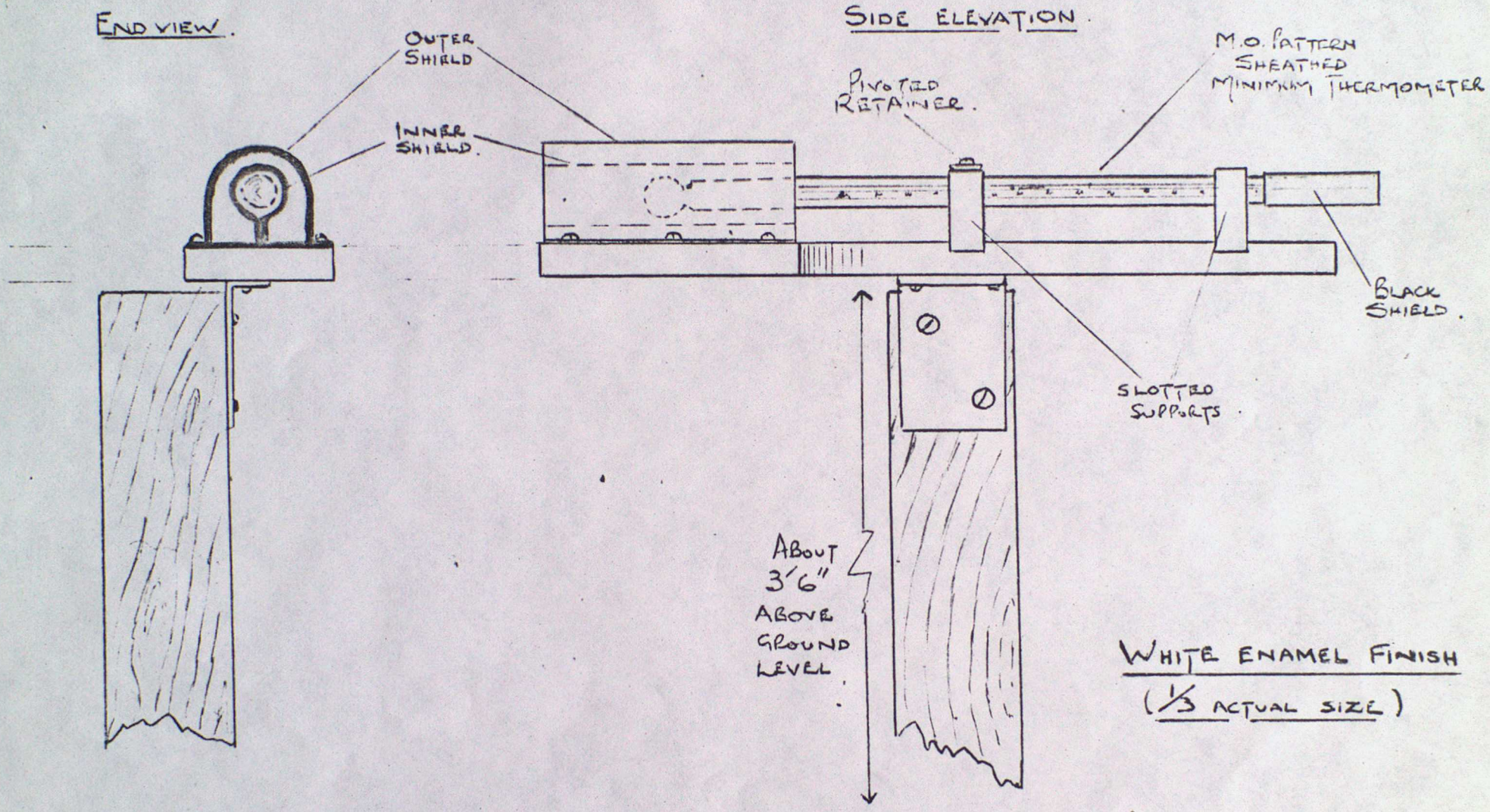
TABLE 2 FROST FREQUENCIES FOR REPRESENTATIVE SITE AT LUDDINGTON GIVEN BY 1975 SURVEY

Showing the number of years in 10 when at least one occasion is expected between the starting dates given and 26 May. Values for $28^{\circ}F$ only are shown

		STARTING DATE							
		APR 1	APR 8	APR 15	APR 22	APR 29	MAY 6	MAY 13	MAY 20
		[redacted]							
SITE 1 (BASE)	*A	6.5	4.3	3.1	2.0	1.5	0.6	0.3	0.1
	*B	6.5	4.3	3.1	2.0	1.5	0.6	0.3	0.1
	C	4.1	3.4	2.3	1.7	1.1	0.4	0.1	(0.0)
(*ACTUAL FREQUENCIES)									
SITE 12	A	8.2	6.6	5.4	4.2	3.5	1.7	1.0	0.6
	B	7.0	4.9	3.6	2.4	1.8	0.8	0.4	0.2
	C	4.5	3.6	2.7	2.0	1.3	0.6	0.2	(0.0)
	D	8.3	6.9	5.8	4.5	3.8	1.9	1.0	0.6
SITE 18	A	8.5	7.4	6.4	5.1	4.3	2.2	1.2	0.8
	B	7.6	6.0	4.6	3.2	2.7	1.2	0.7	0.4
	C	7.0	4.9	3.6	2.4	1.8	0.8	0.4	(0.0)
	D	8.8	7.8	6.9	5.6	4.7	2.5	1.3	0.8

KEY
- A Base Station Luddington: using mean of differences on radiation nights
- B Base Station Luddington: using mean of all differences
- C Base Station Ross-on-Wye: using mean of all differences
- D Base Station Luddington: using mean of differences on 5 radiation nights selected at random.

FIGURE 1.. THERMOMETER MOUNT AS USED IN FROST SURVEYS.



WHITE ENAMEL FINISH

(1/3 ACTUAL SIZE)

FIGURE 2. FREQUENCY OF DIFFERENCES OF DAILY MINIMUM TEMPERATURES BETWEEN TWO SITES ON A SOUTH FACING SLOPE NEAR HEREFORD, AND THE BASE STATION (ROSS. ON. WYE). (APRIL - MAY 1973)

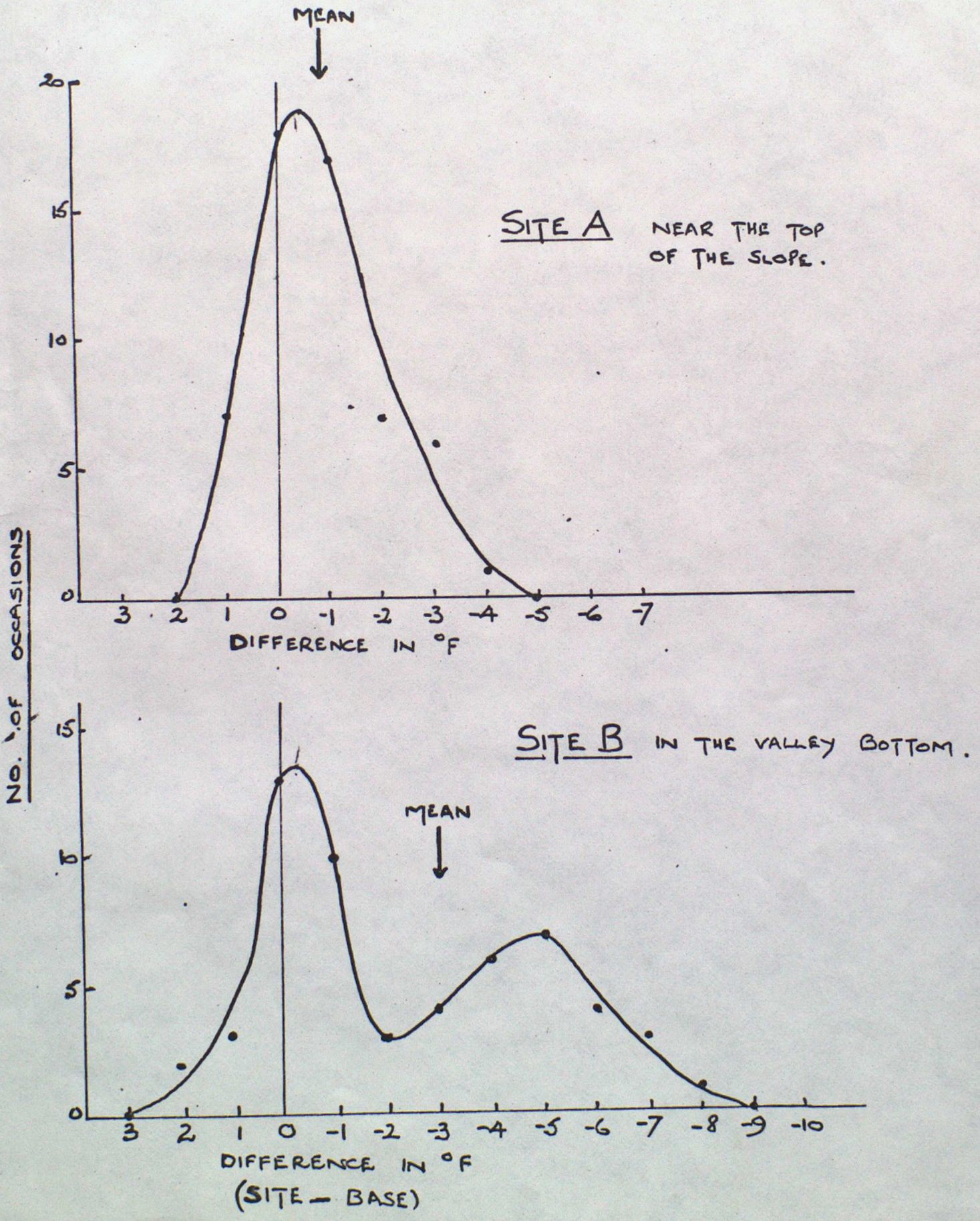


FIGURE 3. LUDDINGTON EHS

SHOWING LOCATION OF THERMOMETERS IN 1975 FROST SURVEY

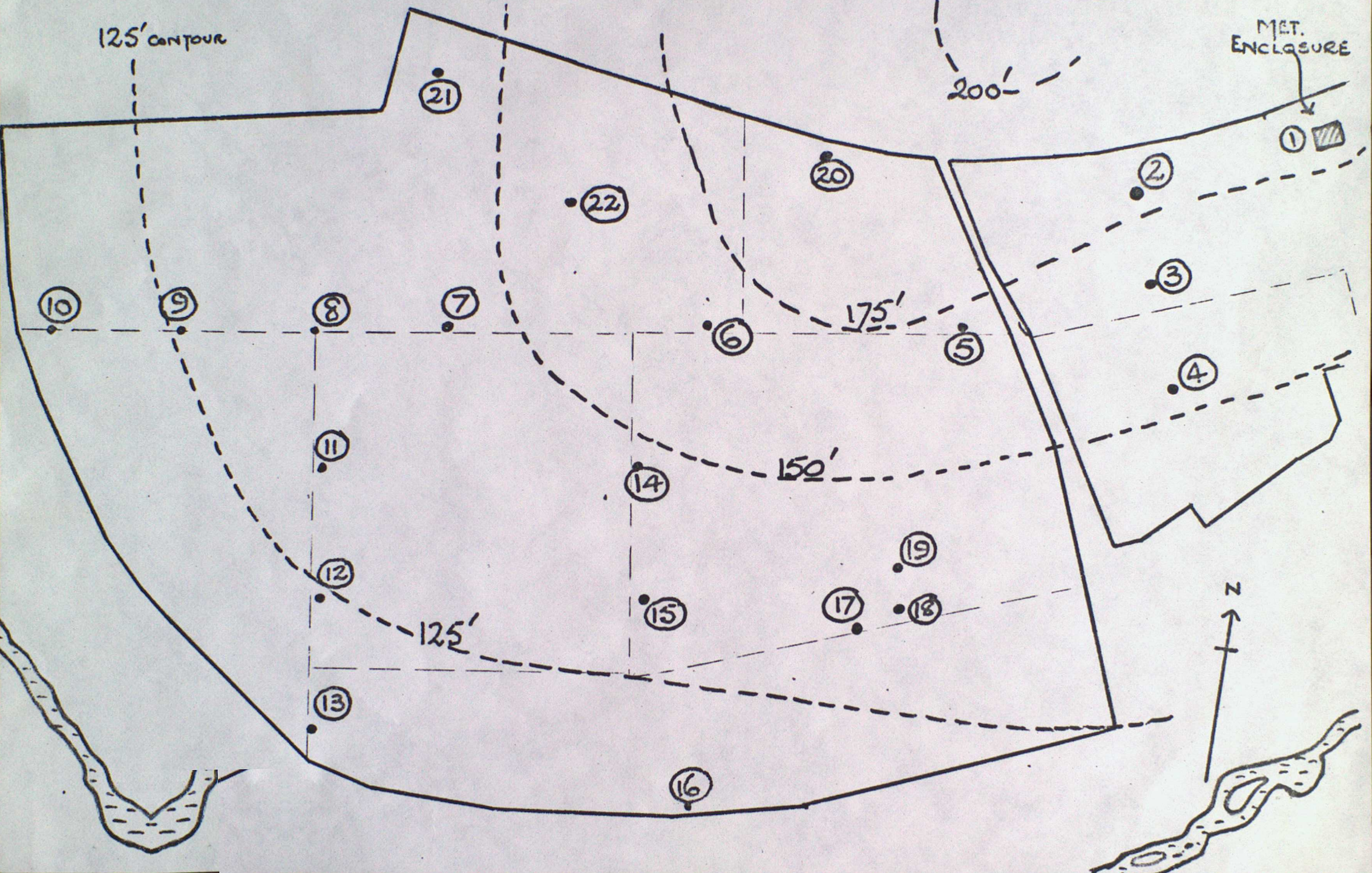


FIGURE 4 LUDDINGTON EHS

APRIL-MAY 1975. DIFFERENCES OF MIN TEMP ON RADIATION NIGHTS (AVERAGE OF 18 OCCASIONS) IN °F.